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Impulse
Measurements

TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO.
F.A. Fisher FA Fisher	1. Shunts 2. Instru-Ins. Testing 3. Trans.-Techniques	57TP60
		DATE 12-29-57

TITLE

TRANSIENT RESPONSE OF IMPULSE CURRENT SHUNTS

ABSTRACT

FOR USE OF G-E EMPLOYEES ONLY

GENERAL ELECTRIC

TRANSFORMER AND ALLIED PRODUCTS DIVISION

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ABSTRACT

The response of various impulse current shunts to an approximate step function of current was investigated. The effects on the transient response of different shunt constructions are reported.

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CONCLUSION

1. The general transient response of impulse current shunts may be investigated and explained in terms of the response to a step function of current. A circuit has been devised which will produce an approximate step function of current through a shunt.

2. The response voltage of a typical shunt of hairpin construction to a step function contains a large inductive component.

3. A coaxial shunt eliminates the component by current positioning of the potential lead.

4. The response of hairpin type shunts may be considerably improved by placing a potential lead along the shunt element.

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For list of contents-drawings, photos, etc. and for distribution see reverse side.

INFORMATION PREPARED FOR High Voltage Laboratory

TESTS MADE BY FA Fisher Tests Completed: September, 1957

COUNTERSIGNED F.A. Fisher FA Fisher SECTION High Voltage Laboratory

BUILDING and ROOM No. #9-102 LOCATION Pittsfield Works

-bfa

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NO PAGES TEXT 15

NO CHARTS

DRAWING NOS.

REF:
EL 4479
DB 701, pp. 39-43
Reports: 50TP91

PHOTO NOS.

PL 120089

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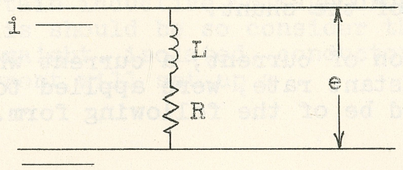
TRANSIENT RESPONSE OF IMPULSE CURRENT SHUNTS

OBJECT:

The object of these tests was to determine the transient response of impulse current shunts. This was done by measuring the output voltage when the input current was an approximate step function of current. The degree to which the response could be improved by suitable placement of the potential lead was also investigated.

THEORETICAL CONSIDERATIONS:

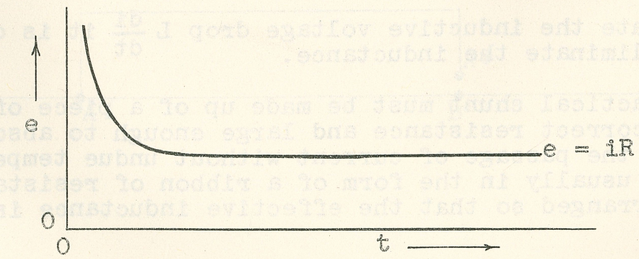
An ideal impulse current shunt would be a pure resistance, but any practical shunt will possess a certain amount of inductance as well, which may lead to significant errors. If the shunt is represented as an inductance in series with a resistance, as below



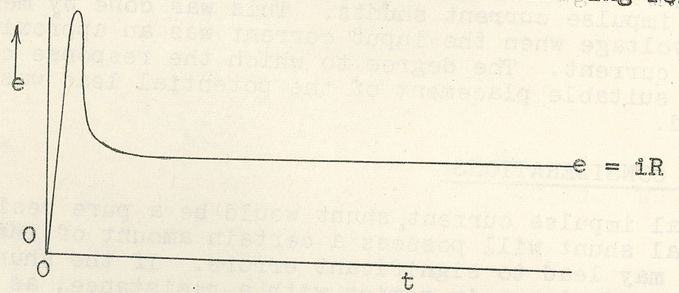
the output voltage e will be

$$e = Ri + L\frac{di}{dt} \qquad (1)$$

If a step function of current is applied, the response voltage would be of the following form.

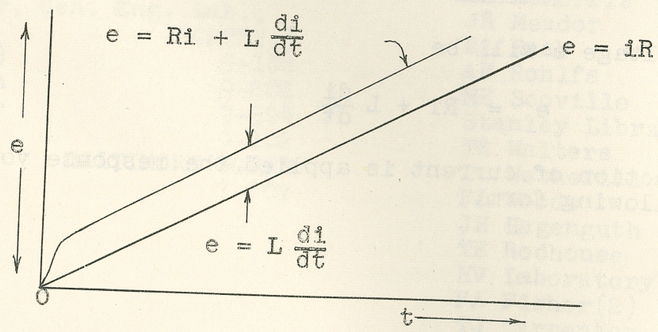


The response voltage would rise immediately to infinity, decay exponentially, and reach a steady state value equal to the resistance voltage drop. Actually of course a step function of current and a shunt possessing no capacitance are only hypothetical. If an approximate step function of current were applied to an actual shunt, the response voltage would be of the following form.



The amplitude of the initial overshoot, assuming a constant wave shape for the applied current, is essentially proportional to the effective inductance of the shunt.

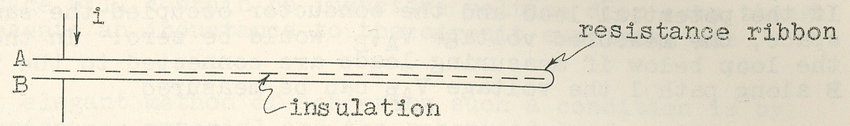
If a ramp function of current, a current which increases indefinitely at a constant rate, were applied to a shunt the response voltage would be of the following form.



To eliminate the inductive voltage drop $L\frac{di}{dt}$ it is of course necessary to eliminate the inductance.

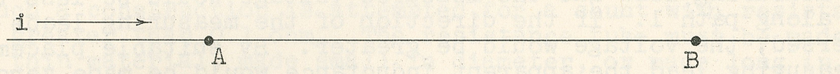
A practical shunt must be made up of a piece of resistance material with the correct resistance and large enough to absorb the heat generated by the passage of current without undue temperature rise. The material, usually in the form of a ribbon of resistance metal, must also be arranged so that the effective inductance is as small as

practical. Generally the ribbon is folded into a hairpin loop with insulation between the two parts and clamped tightly together.

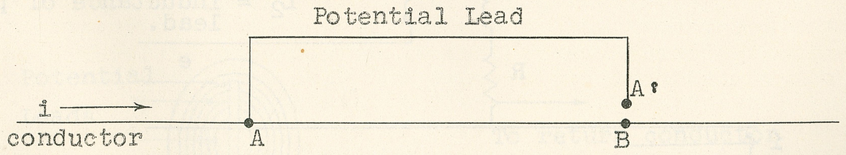


If the ribbon and the insulation were of zero thickness, the total inductance would be zero since all the magnetic flux generated in one half of the loop would link the other half as well, making the net number of flux linkages zero. Since the conductor has a finite thickness and the conductors must be insulated from each other there will be a certain number of net flux linkages and hence a certain inductance which cannot practically be reduced.

Does this then mean that the response voltage V_{AB} must necessarily contain a certain inductive voltage drop? The answer is no and to see why this should be so consider the case of a current flowing through a straight, isolated, conductor containing no resistance. The current will set up a



magnetic flux which produces an inductive voltage drop $V_{AB} = L\frac{di}{dt}$ where L is the self inductance of the conductor. If an attempt is made to measure the voltage however, the measured voltage V_{AB} will be found to vary with the location of the leads to the measuring device. If the potential leads are run near the conductor as below



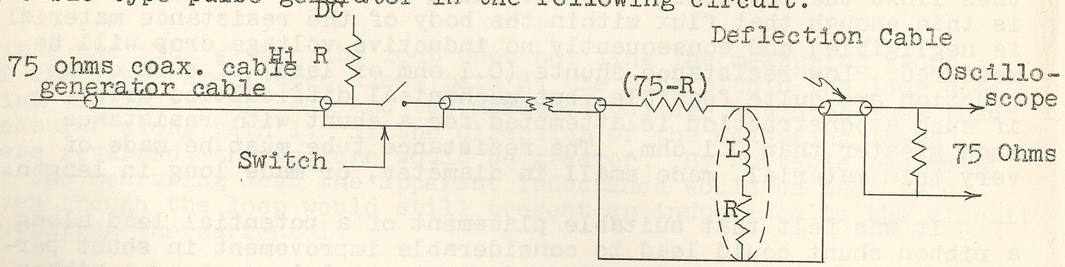
Since the current is not concentrated at the center of the strip the flux density is not uniform and not all of the flux links the entire conductor. A potential lead laid along the center of the ribbon would be linked by more than the average flux linking the ribbon, while a potential lead laid along the edge would be linked by less. For perfect compensation the potential lead should be linked by just the flux equal to the average flux linking the ribbon. This could be done by spacing the potential lead the correct distance from the ribbon, placing it along the ribbon at the correct distance from the edge, or running the potential lead along only the correct portion of the total length of the ribbon. An analytical determination of the correct location is very difficult, but the problem can be tackled experimentally.

EXPERIMENTAL TESTS:

Test Connections

Since the response to a step function defines the response to any wave it was decided to investigate the response of various shunts to approximate step functions of current at low voltages.

An approximate step function of current was generated by using a cable type pulse generator in the following circuit.



When a transmission line, which has been charged through a high resistance, is discharged into a resistor equal to the surge impedance of the line, a step function of current will flow through the resistor. The current pulse lasts twice as long as the travel time of the generator cable. A moderate amount of inductance in the terminating resistor merely slows down the rise time of the current pulse, but does not distort the wave appreciably. When an impulse current shunt is connected in the circuit as above, the current is primarily controlled by the added resistor, which is usually very near 75 ohms.

The pulse generator used was capable of developing 100 volts across a 75 ohm resistor thus producing a current of 1.3 amperes.

Such a current through a shunt produces a response voltage which can be amplified and displayed on an oscilloscope. A Tektronix 545 oscilloscope with a 53/54K preamplifier was used.

Shunts Tested and Results

The following current shunts were tested first:

0.0238 ohms - hairpin construction
0.05380 ohms- hairpin construction
0.25 ohms - hairpin construction
0.9346 ohms - hairpin construction

0.02 ohms - coaxial shunt

(1) 5 ohm non-inductively wound resistor card
(2) 5 ohm non-inductively wound resistor cards, in parallel

Photographs of these shunts are shown on PL 120089. Tracings of the response wave oscillograms are shown on Figures 1 and 2. The inductive voltage drop during the rising portion of the applied wave was quite pronounced with the hairpin shunts and the resistor cards. While the limited performance of the oscilloscope amplifier resulted in the overshoot being reproduced with less than its true amplitude and more than its true width the performance of various shunts could still be compared. The coaxial shunt gave an almost perfect reproduction of the applied wave.

To determine the effect of potential lead placement a highly inductive shunt was built as shown on Figure 3. The response was determined with a #27 cotton and enamel covered copper potential lead arranged in the five different locations shown. Tracings of the resulting response waves are shown on Figures 4 and 5. Figure 4 shows the input wave and uncompensated response waves displayed directly on the plates of the oscilloscope to eliminate the distortion caused by the amplifier. Figure 4 also shows the response wave as passed through the amplifier. The amplifier reduced the relative magnitude of the measured inductive drop and lengthened the duration. Figure 5 shows the effect of various potential lead arrangements. The initial spike was not reduced appreciably, which may indicate it was caused partly by an increased resistance due to skin effect during the fast rising portions of the applied current wave. Definite changes were noted on the tail of the response wave however. With the potential lead near the center the response sloped upward indicating that the lead was linking more than the average flux linking the resistance ribbon. With the lead at the edge the response sloped down indicating the lead was linking less than the average flux. The possibility of overcompensation did exist then, but the response could be considerably improved.

75
1.3
225
75
97.5

The shunt was then rebuilt with the spacing between the two halves of the resistance ribbon reduced to a more realistic 0.01 inch. The resulting response waves are shown on Figure 6. The effect of potential lead placement was no longer as pronounced, presumably because the total inductance of the loop had been reduced due to coupling between the two halves of the resistance ribbon. The tendency toward over or under compensation still existed, but the effect lasted for a much shorter time. The relative magnitude of the inductive drop was larger since the potential lead could not be held as close to the body of the resistance ribbon. Also shown is the response when a strip of foil as wide as the resistance ribbon was used as the potential lead. The width of the spike was less because the self-inductance of the potential lead was lower.

As a final check a shunt was built with dimensions as shown on Figure 3C. The spacing between the potential lead and the ribbon and between halves of the ribbon was reduced to about 3 mils, and the entire structure clamped tightly together. A ribbon was used as the potential lead to reduce its inductance and to facilitate mechanical assembly. Figure 7 shows the response waves measured directly between points A and B and measured using the potential lead.

The wiggle in the middle of the response waves was probably due to a reflection in the coaxial connections to the pulse generator. The response of the shunt was markedly improved by the use of the potential lead. The inductive drop was greatly reduced while no apparent tendency toward overcompensations was seen.

CONCLUSIONS:

While no apparent tendency toward overcompensation was seen on the shunt of Figure 3C when using a ribbon potential lead it must be remembered that this was a rather high resistance shunt, 0.245 ohms. In shunts of low resistance the inductive drops are more important and compensation for inductance might be more critical. Coaxial shunts, which are inherently compensated for inductive drops, might then be used wherever feasible. Where the expense of a coaxial shunt is not justified, or where the desired resistance is too high for a coaxial shunt to be practical, the hairpin type of shunt with a ribbon potential lead could be used to good advantage. Such a construction, in the higher resistance ranges at least, results in a shunt with a transient response nearly as good as a coaxial shunt.

RESPONSE OF VARIOUS UNCOMPENSATED
HAIRPIN TYPE IMPULSE CURRENT SHUNTS

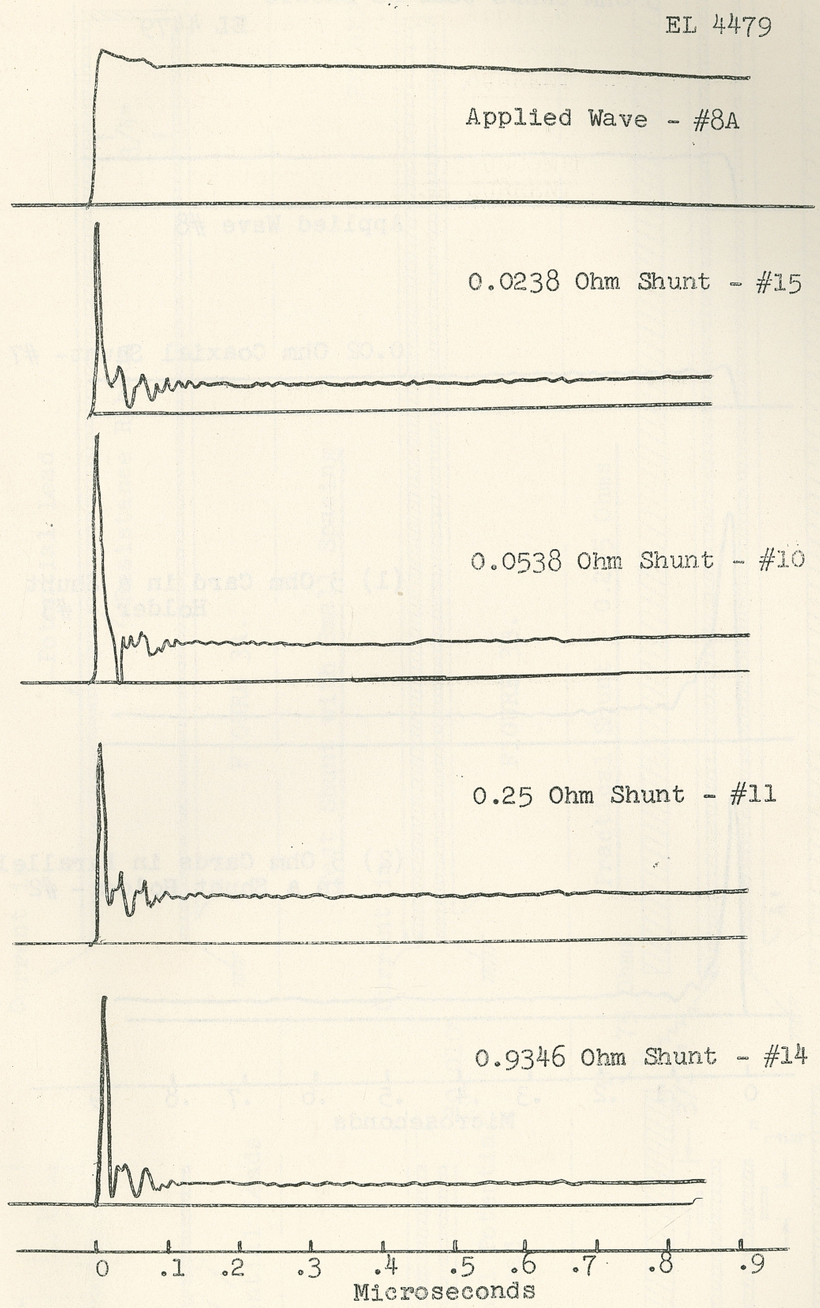
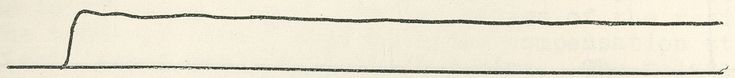


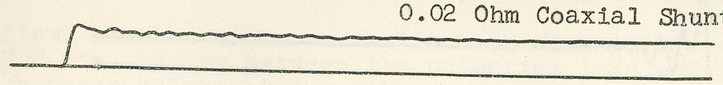
FIGURE 1.

RESPONSE OF A COAXIAL SHUNT AND
5 OHM CARDS USED AS SHUNTS

EL 4479



Applied Wave #8



0.02 Ohm Coaxial Shunt- #7

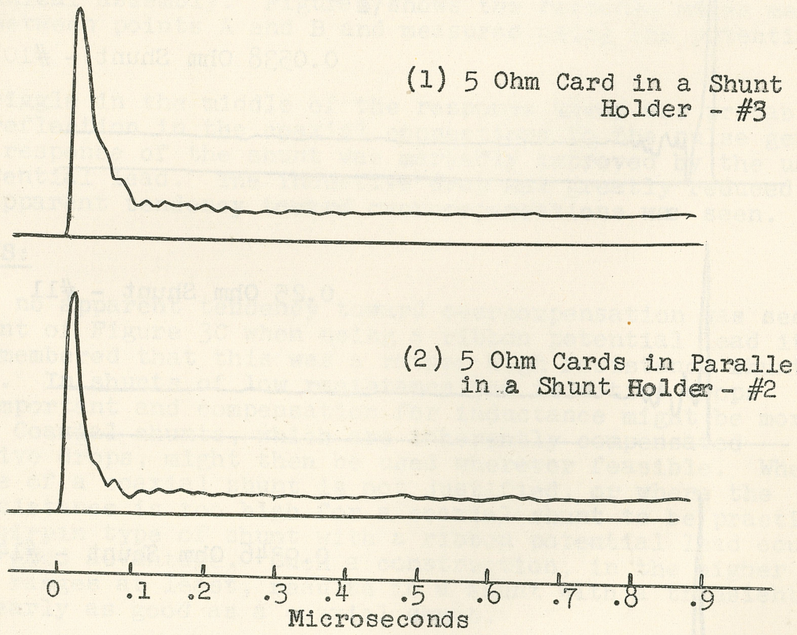
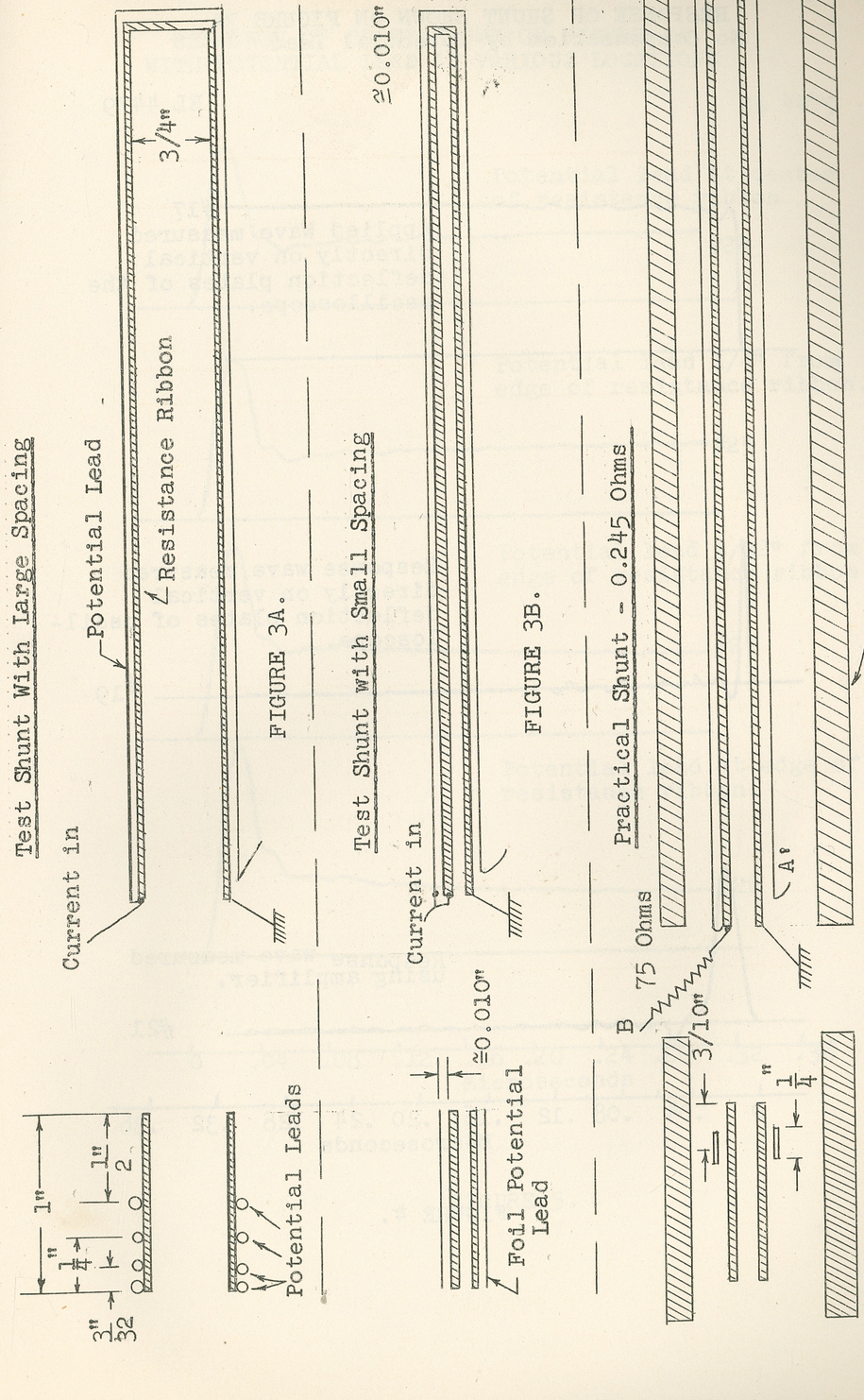


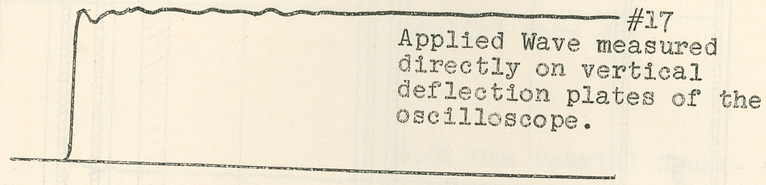
FIGURE 2.

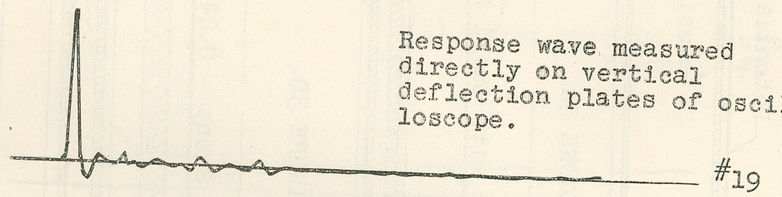
SHUNT AND POTENTIAL LEAD ARRANGEMENTS



RESPONSE OF SHUNT SHOWN ON FIGURE 3A
No Compensation by Potential Lead

EL 4479





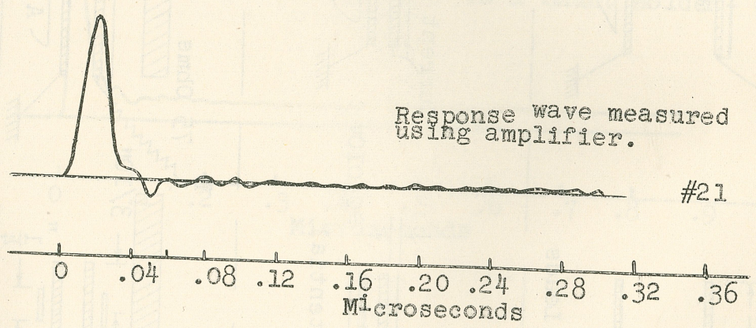


FIGURE 4.

RESPONSE OF SHUNT SHOWN ON FIGURE 3A
WITH POTENTIAL LEAD AT VARIOUS LOCATIONS

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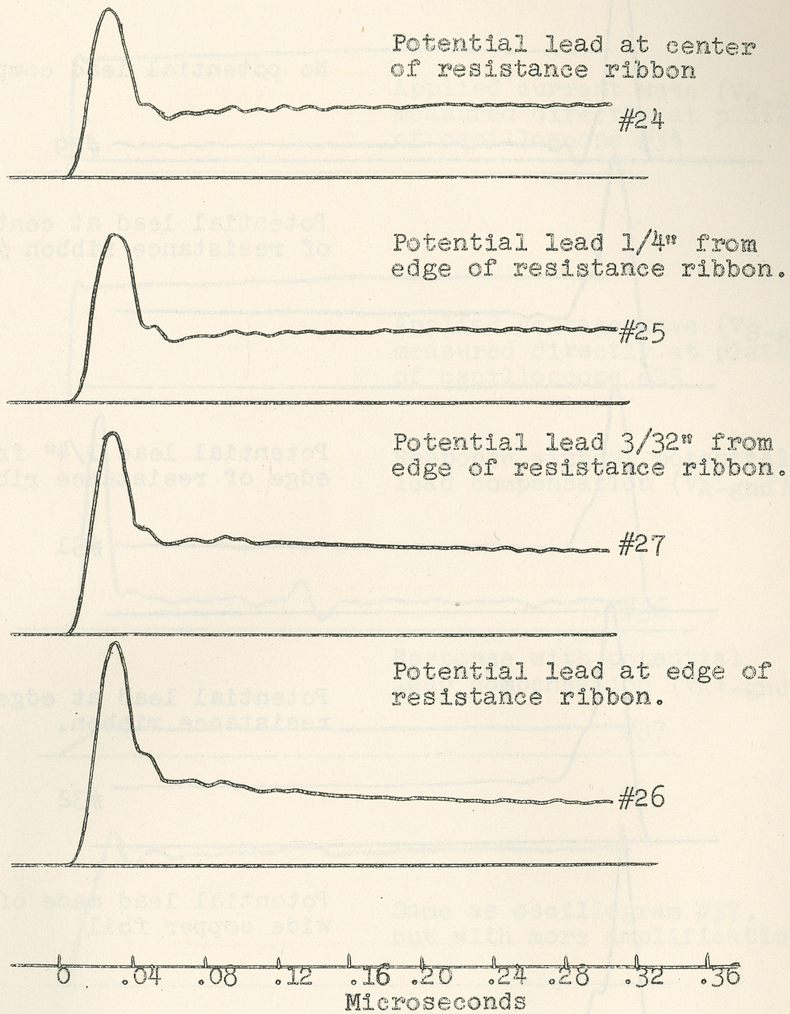

Potential lead at center of resistance ribbon
#24
Potential lead 1/4" from edge of resistance ribbon.
#25
Potential lead 3/32" from edge of resistance ribbon.
#27
Potential lead at edge of resistance ribbon.
#26
0 .04 .08 .12 .16 .20 .24 .28 .32 .36
Microseconds

FIGURE 5.

RESPONSE OF SHUNT SHOWN ON FIGURE 3B
WITH POTENTIAL LEADS AT VARIOUS LOCATIONS

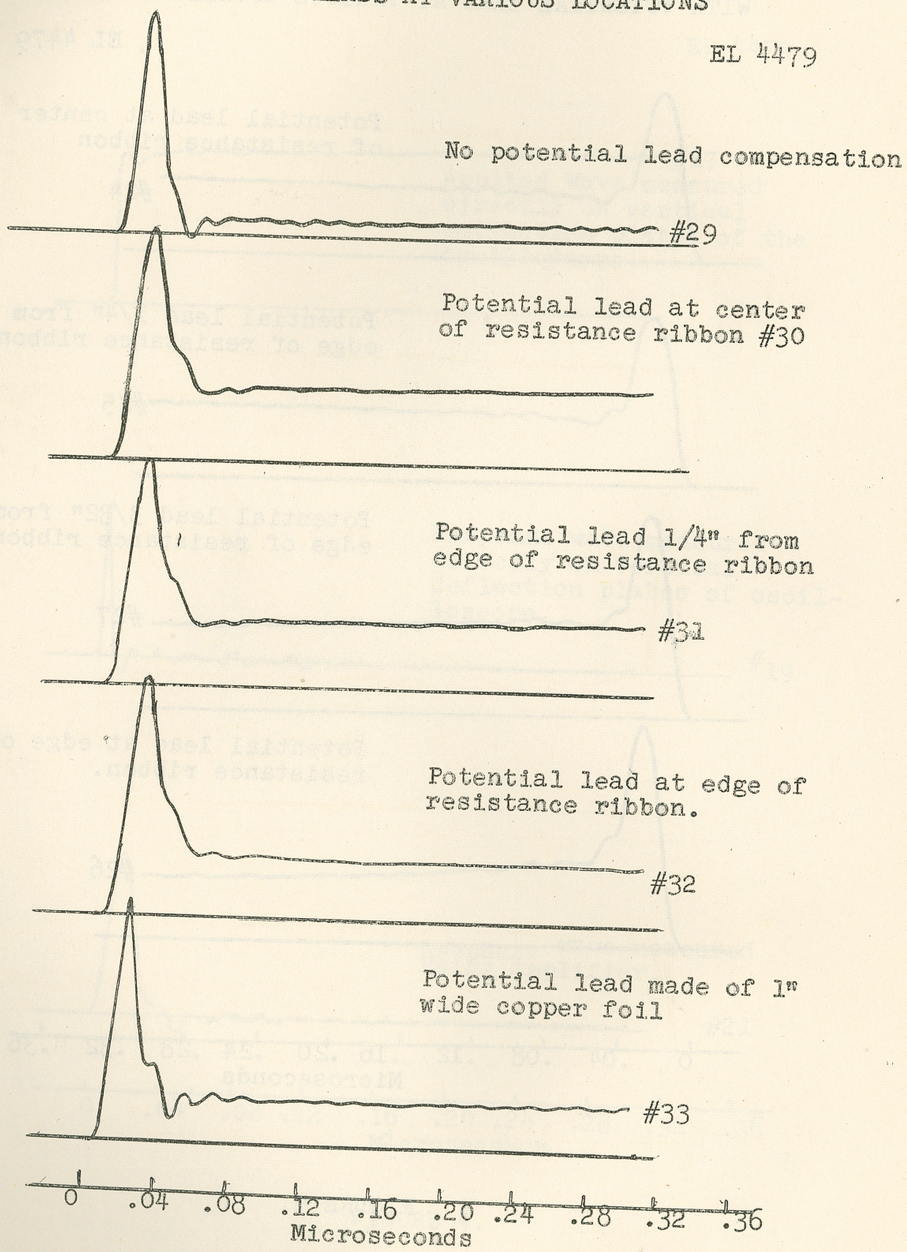

EL 4479
No potential lead compensation
#29
Potential lead at center of resistance ribbon #30
Potential lead 1/4" from edge of resistance ribbon
#31
Potential lead at edge of resistance ribbon.
#32
Potential lead made of 1" wide copper foil
#33
0 .04 .08 .12 .16 .20 .24 .28 .32 .36
Microseconds

FIGURE 6.

RESPONSE OF SHUNT SHOWN ON FIGURE 3C

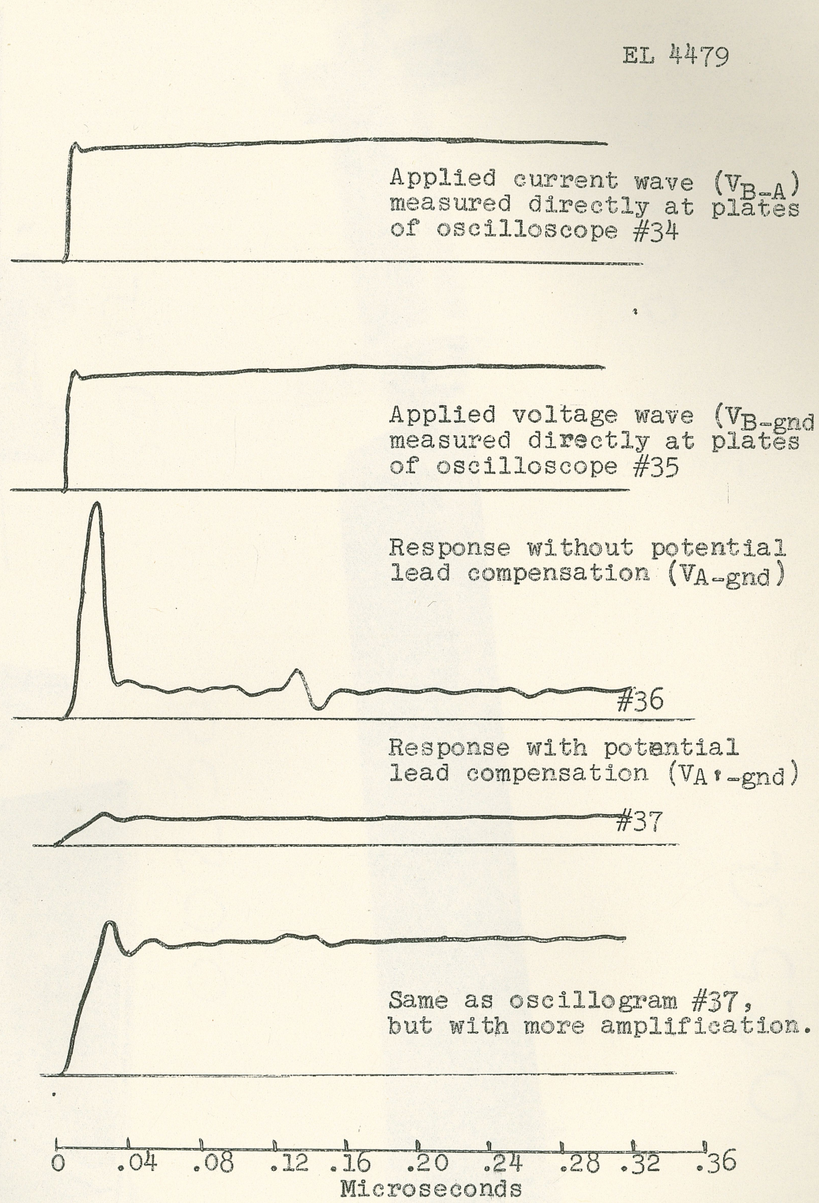
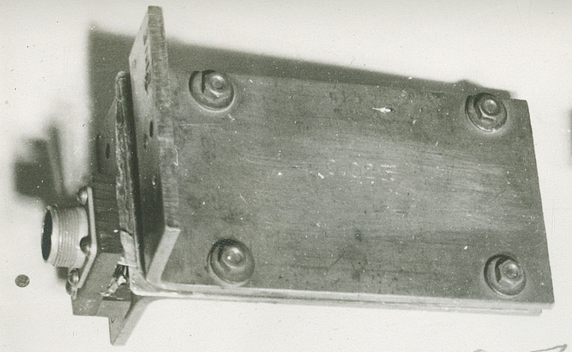
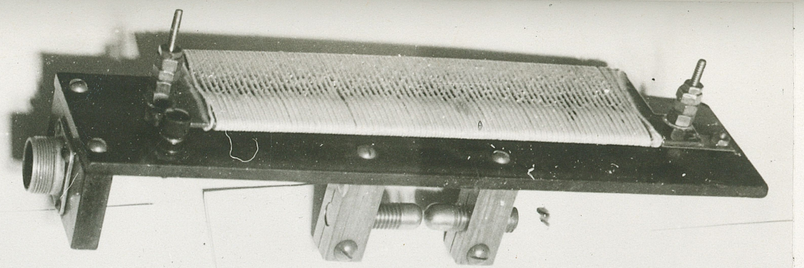

EL 4479
Applied current wave (V_{B-A}) measured directly at plates of oscilloscope #34
Applied voltage wave (V_{B-gnd}) measured directly at plates of oscilloscope #35
Response without potential lead compensation (V_{A-gnd})
#36
Response with potential lead compensation ($V_{A'-gnd}$)
#37
Same as oscillogram #37, but with more amplification.
0 .04 .08 .12 .16 .20 .24 .28 .32 .36
Microseconds

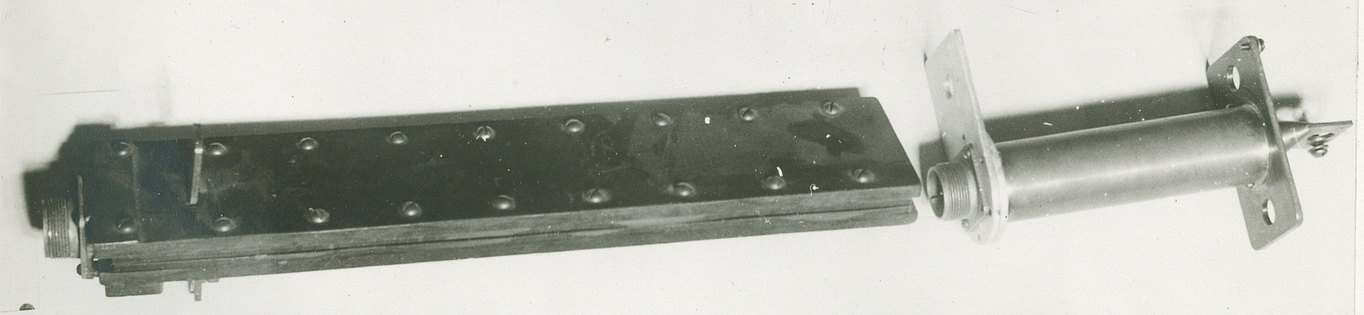
FIGURE 7.



0.0238



5.0 Ω



0.25 Ω

0.02 Ω
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